Lower Mokelumne River Salmonid Redd Survey Report:
October 2016 through December 2016

July 2017

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Abstract

Weekly fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and winter-run steelhead/rainbow trout (*Oncorhynchus mykiss)* spawning surveys were conducted on the lower Mokelumne River from 12 October 2016 through 20 December 2016. Estimated total escapement from video monitoring during the 2016/2017 season was 8,871 Chinook salmon. The estimated number of in-river spawners was 1,984 Chinook salmon. The first salmon redd was detected on 26 October 2016. During the surveys, 405 salmon redds were identified. Twenty seven (6.7%) Chinook salmon redds were superimposed on other Chinook salmon redds and 223 (55.1%) redds were located within spawning habitat restoration sites. The reach from Camanche Dam to Mackville Road (reach 6) contained 322 (80%) salmon redds and the reach from Mackville Road to Elliott Road (reach 5) contained 83 (20%) salmon redds. The highest number of Chinook salmon redds (99) was detected during survey week 8 (28 November and 2 December 2016). Four *O. mykiss* redds were identified during the surveys. The first *O. mykiss* redd was found on 6 December 2016. *O. mykiss* redd surveys ended prematurely after 20 December, due to unsafe Camanche releases exceeding 4,900 cubic feet per second.

INTRODUCTION

The Mokelumne River is an east-Delta tributary that drains more than 1,642 square kilometers (600 square miles) of the western slope of the Sierra Nevada with headwaters at an elevation of 3,048 meters (10,000 feet) on the Sierra Nevada Crest (Jones and Stokes 1999). The Mokelumne River currently has 16 major water impoundments including Salt Springs Reservoir, Lower Bear River Reservoir, Pardee Reservoir and Camanche Reservoir. Water releases to the lower Mokelumne River (LMR) are controlled by Camanche Dam. The LMR is approximately 103 river kilometers (rkm) in length from the confluence with the San Joaquin River (rkm 0) and Camanche Dam (the first major impoundment and limit to anadromy, rkm 103). The construction of Camanche Dam was completed in 1963 and blocked upstream passage of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) to much of the available historical spawning habitat in the Mokelumne River. Most of the available spawning habitat in the LMR is now limited to the 15.8 km (9.8 mile) section of river directly downstream of Camanche Dam (Setka and Bishop 2003).

Pardee and Camanche reservoirs and associated power generating facilities are owned and operated by the East Bay Municipal Utility District (EBMUD) and regulated by the Federal Energy Regulatory Commission (FERC Project P-2916). EBMUD provides water for approximately 1.3 million customers in Alameda and Contra Costa counties. Additional reservoirs and power generation facilities are located upstream of Pardee Reservoir and are owned and operated by Pacific Gas & Electric Company (PG&E). Downstream of Camanche Dam, Woodbridge Irrigation District (WID) operates Woodbridge Irrigation District Dam (WIDD) and an associated system of irrigation canals near Lodi, CA.

The LMR is utilized for spawning and rearing by fall-run Chinook salmon and both resident and anadromous forms of *O. mykiss*. Adult Chinook salmon ascend the LMR as early as August and may begin spawning as early as September. Spawning activity usually peaks in November and tapers off through the month of December (Hartwell 1996; Marine and Vogel 1994; Setka 1997). The Mokelumne River Fish Hatchery (MRFH) was constructed in 1964 to mitigate for spawning habitat lost during the construction of Camanche Dam and receives approximately 58% of the total run per year (1990-2015 average). EBMUD has conducted annual spawning surveys on the LMR since 1990 (Hagar 1991; Hartwell 1996; Setka 1997). EBMUD conducts video monitoring at WIDD to assess the upstream passage of anadromous fishes. Video monitoring provides an escapement estimate of the total number of Chinook salmon and steelhead returning to the LMR each season.

OBJECTIVES

The primary objective of the 2016/2017 salmonid redd surveys (referred to as the 2016 season) was to enumerate Chinook salmon and *O. mykiss* redds in the LMR. Additional objectives of the redd surveys included:

- Determine the spatial and temporal distribution of redds in the LMR;
- Enumerate redds impacted by superimposition; and
- Determine use of spawning habitat restoration (SHR) sites.

METHODS

Surveys

The LMR is divided into six reaches between Camanche Dam and the confluence with the San Joaquin River. Reach delineations are based on gradient, substrate, and tidal influence. The majority of available salmonid spawning habitat on the LMR occurs in reaches 5 and 6. Therefore, redd surveys were conducted within reaches 5 and 6. Specifically, the surveys took place within a 16 km reach, from rkm 103 (the base of Camanche Dam) downstream to rkm 87.4 (Figure 1). Weekly redd surveys began on 12 October 2016 and

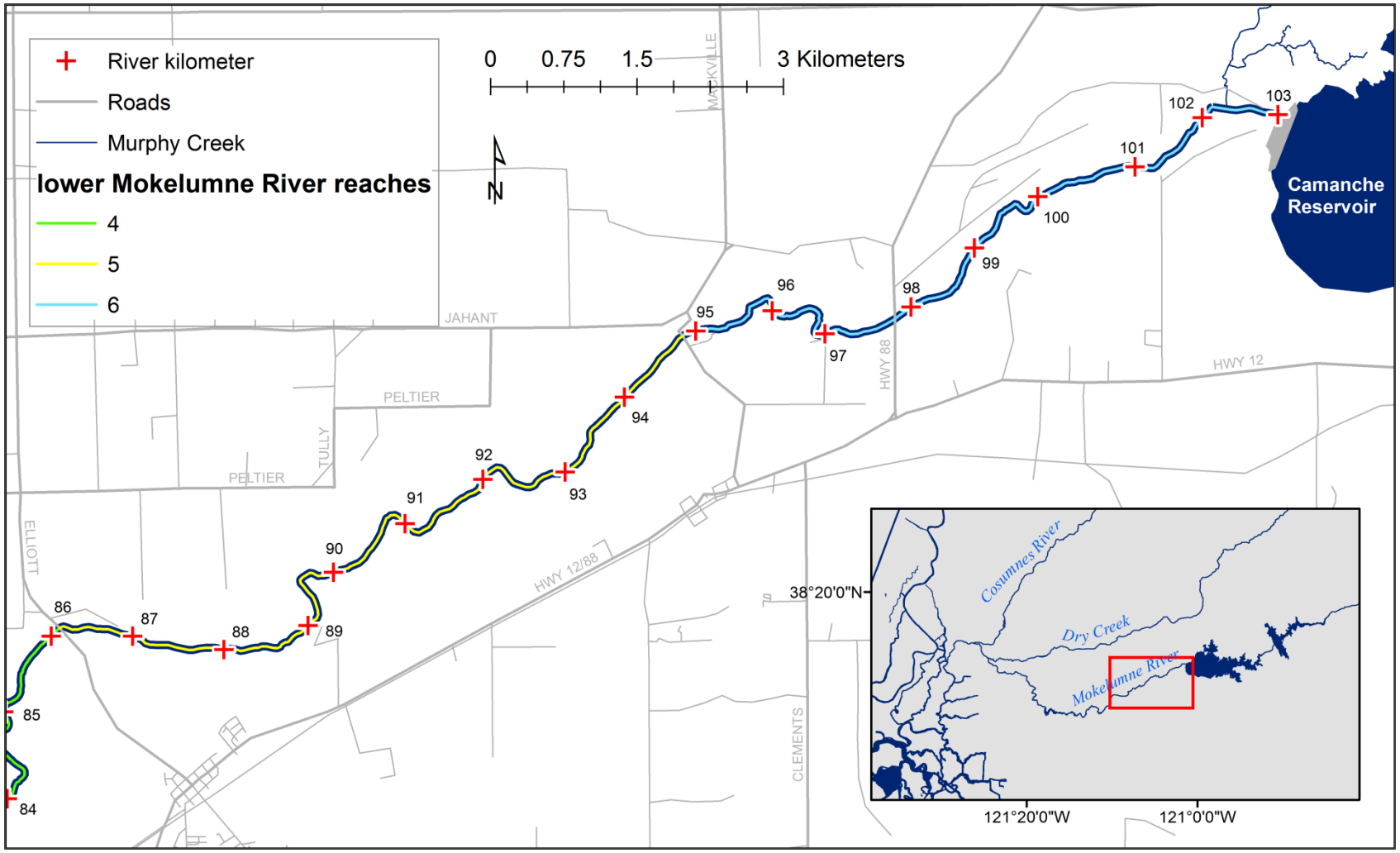

Figure 1. The location of river reaches 5 and 6 on the lower Mokelumne River, where salmonid redd surveys took place during the 2016 season.

ended early on 20 December 2016, due to a wet winter and high flood control releases from Camanche. Both reaches were surveyed once per week during this time frame. Surveys consisted of two to three individuals walking abreast downstream (water depths up to 1.1 meters) searching for redds. This method has been used in past LMR spawning surveys and in other rivers and streams (Keefe et al. 1994; Fritsch 1995; Hartwell 1996; Setka 1997). Kayaks or a drift boat were used to transport surveyors between spawning areas and were also used to search for redds in areas that were not wadeable.

Trimble Geo XH Global Navigation Satellite Systems (GNSS) were used to record the location of salmonid redds (<1 meter real-time accuracy). The GNNS units also allowed the surveyors to display previously recorded data in the field. The ability to see data from previous surveys eliminates the need to physically mark redds and reduces the potential of counting a redd more than once. Surveyors positioned themselves directly downstream of each redd and recorded the position of the tailspill. Care was taken to avoid impacting redds during the surveys.

Surveyors determined if previously detected redds were superimposed based on the amount of time that had elapsed since a redd was first detected. A 3-week (21 days) filter was used to help distinguish older redds from newly constructed redds. The filter was based on the estimated life of fall-run Chinook salmon redds (Gallagher et al. 2007). All visible occurrences of redd superimposition were recorded.

To assess spatial and temporal variability, water depth and velocity measurements were measured from roughly one in every 10 redds and recorded just above the nose of Chinook salmon redds during the first nine weeks of the 2016 surveys. High flows prevented surveyors from taking measurements during the last two weeks of the surveys.Water depth measurements were recorded to the nearest centimeter (cm) using a top-setting rod. Velocity measurements were taken using a Flo-Mate™ portable velocity meter (Marsh McBirney, Inc.) at 60% of the depth and recorded in meters per second (m/s).

Surface water temperature and flow data were obtained from EBMUD gauging stations at Camanche Dam (rkm 103), McIntire (rkm 101), and Elliot Road (rkm 86). In addition sixteen HOBO TidbiT© waterproof temperature loggers were buried below the gravel surface on 5 and 26 October 2016 to record hourly subsurface water temperatures. Two temperature loggers were buried at depths of 25 cm and 40 cm within eight spawning sites between Camanche Dam (rkm 103) and Elliot Road (rkm 86). A Trimble Geo XH™ GNSS unit was used to mark the burial locations of the temperature loggers.

Data Collection and Analysis

A minimum of ten points were recorded on the GNSS unit at each redd location and point data files were stored using Terrasync 5.21 software. After field data were collected, the data files were downloaded and processed using GPS Pathfinder Office 5.30 software. Once downloaded, geographic positions were corrected using the nearest base data providers. The data files were then imported to an ArcMap 10.2 (ESRI) database.

Data analyses were performed using ArcMap 10.2 (Arc/Info (ESRI) systems), JMP 9.0.0 (Academic), Microsoft (MS) Access 2010 and MS Excel 2010. A *P*-value ≤ 0.05 was considered statistically significant.

RESULTS

Environmental Data

In 2016, a series of pulse flows were released throughout October, November, and the beginning of December (Figure 2). Average daily flow from Camanche Dam peaked at 901 cubic feet per second (cfs) during the largest pulse event and peaked between 820 and 503 cfs during nine other pulse events. The 2016 survey ended when Camanche releases increased from 955 cfs on 20 December to releases above 4,900 cfs .

During the redd survey period (12 October 2016 – 20 December 2017) average daily discharge from Camanche Dam ranged from 275 to 955 cfs (Figure 2). The average daily flow during this time period was 508 cfs. The average daily flow when Chinook salmon redds were detected (26 October 2016 through 20 December 2016) ranged from 330 to 955 cfs and averaged 517 cfs. The average daily flow that *O. mykiss* redds were detected (6 December 2016 through 20 December 2016) ranged from 450 cfs to 955 cfs and averaged 751 cfs.

Average daily surface water temperatures at the McIntire gauging station (rkm 101, reach 6) ranged from 12.6°C to 14.0°C during the survey period (Figure 2). The average temperature during this time frame was 13.7°C. The average daily water temperatures during the time period salmon redds were detected (26 October 2016 through 20 December 2016) ranged from 12.6°C to 14.0°C and averaged 13.7°C. The average daily water temperatures during the time period when *O. mykiss* redds were detected (6 December 2016 through 20 December 2016) ranged from 12.6°C to 13.7°C and averaged 13.4°C.

Over the last five spawning and incubation seasons (2012-2016) average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire and Elliot Rd. gauges, regardless of burial depth (Figure 3). Although there were periods of time when average daily hyporheic water temperatures were marginally higher than surface water temperatures. Each season, over 95% of all salmon redds were constructed when all water temperatures were below 16.4°C, with the exception of 2014, when surface water temperatures at the McIntire gauge were just above 16.4°C for a short time in October and November.

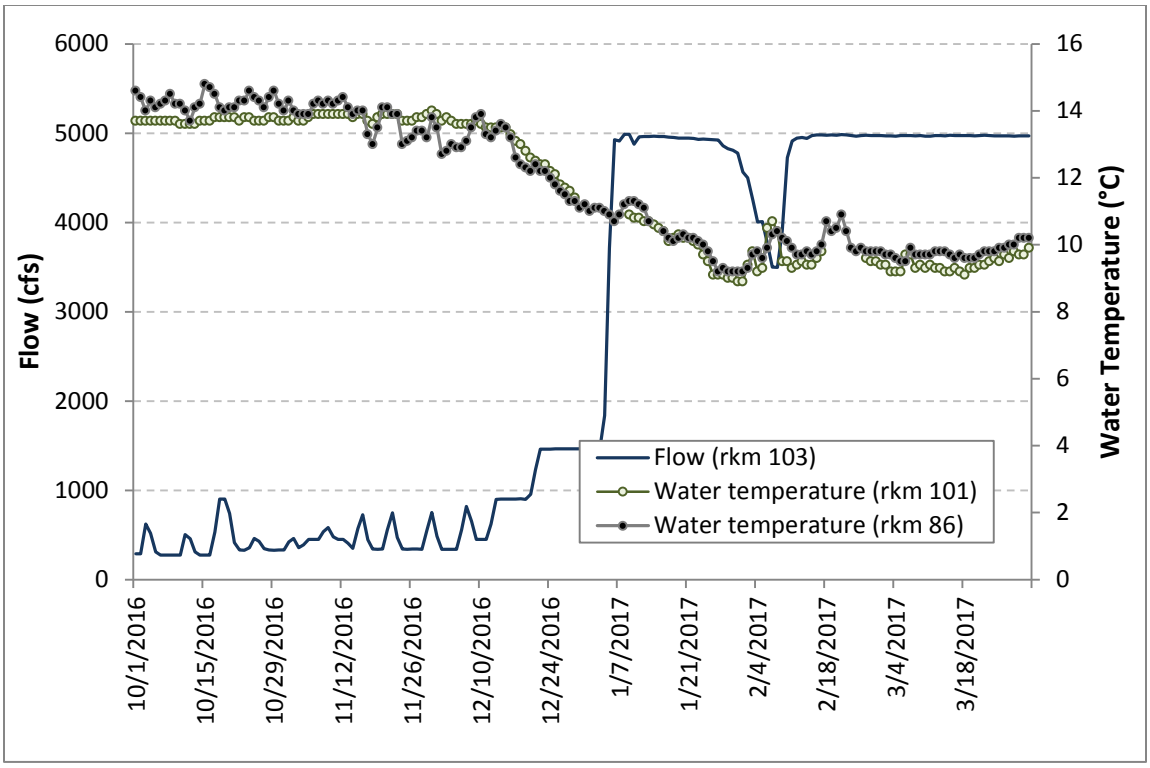

Figure 2. Average daily discharge from Camanche Dam (rkm 103) and average daily surface water temperatures at the McIntire gauging station (rkm 101) and the Elliot Road gauging station (rkm 86) in the lower Mokelumne River during the 2016 salmonid redd surveys.

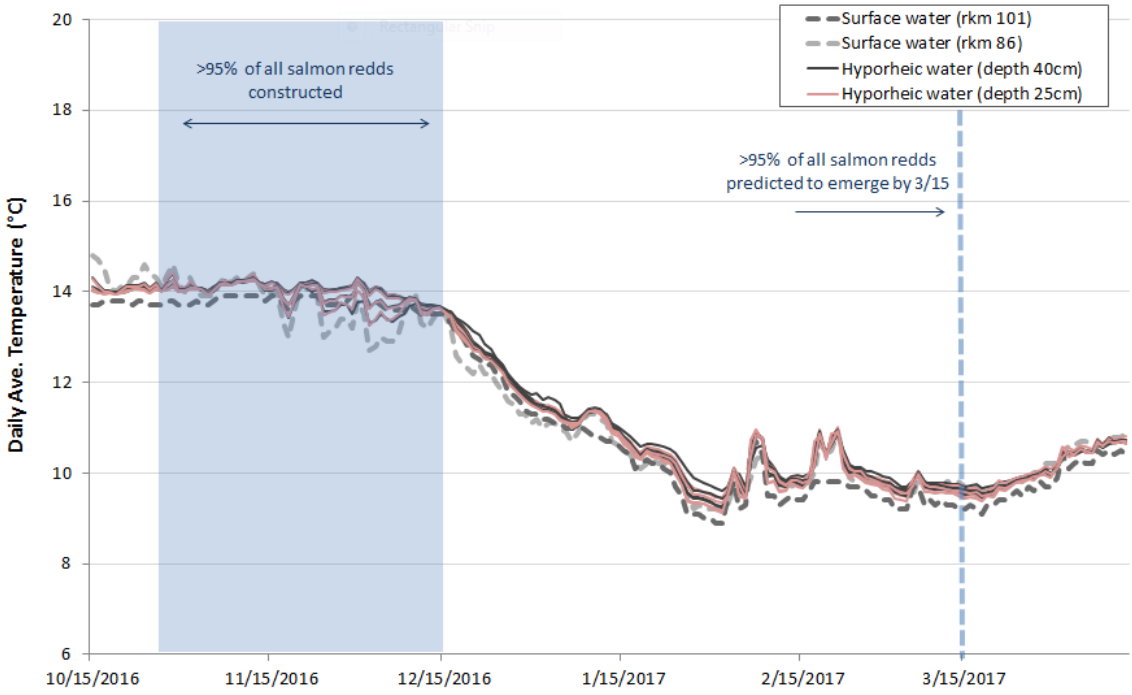

Figure 3. Average daily surface and subsurface (hyporheic) water temperatures recorded on the lower Mokelumne River during the 2016 redd survey season.

Redd totals and escapement

During the 11 week redd survey period, 405 Chinook salmon redds were detected. The first and last redd detections occurred on 26 October 2016 and 20 December 2016, respectively. The highest number of redds (99) were detected during survey week 8 on 28 November and 2 December 2016 (Figure 4). Reach 6 contained 322 redds (80%) and reach 5 contained 83 redds (20%).

The 2016 annual redd count was 50% of the long term average (1990-2015) of 802, 65% of the pre-Joint Settlement Agreement (JSA) average (1990-1997) of 625, and 47% of the post-JSA average (1998-2015) of 881 (Figure 5). Low redd counts for 2016 were due to a truncated survey season due to flood control releases from Camanche.

To estimate fall-run Chinook salmon escapement in the LMR during the 2016 season, video monitoring was conducted at WIDD between 1 August 2016 and 6 January 2017. An estimated 8,871 Chinook salmon passed through the fish ladders at WIDD. The total count of Chinook salmon that entered the MRFI this season was 6,887.

The LMR in-river escapement estimate of 1,984 fall-run Chinook salmon was calculated by subtracting the MRFI salmon count from the video monitoring count at WIDD. Approximately 52% (4,592) of the Chinook salmon that returned to the LMR were classified as adults, while the remaining 48% (4,273) were classified as grilse. Less than 1% (6) could not be determined. Sexual composition of the run was 57% (5,095) male, 43% (3,770) female, and less than 1% (6) could not be determined.

Spawning habitat restoration site use

During the 2016 redd survey, 164 (40.5%) Chinook salmon redds were found within the restored upper 1.3 rkm reach, just below Camanche Dam (SHIRA reach – Spawning Habiat Integrated Rehabilitation). Overall, 223 (55.1%) Chinook salmon redds were constructed within SHR sites. In reach six, 182 redds (81.6%) were constructed in SHR sites. Forty-one salmon redds (18.4%) were constructed in SHR sites in reach 5.

Superimposition

Twenty-seven Chinook salmon redds (6.7%) were superimposed on other Chinook salmon redds during the 2016 redd survey season. Most of the superimposition took place in reach 6 (24 redds), while just three redds were superimposed in reach 5.

The 2016 superimposition rate was lower than the long-term average of 10.6% of average (1991-2015), the pre-JSA average of 9.0% of average (1991-1997) and the post-JSA average of 11.2% of average (1998-2015). There was a significant positive linear relationship between the annual redd count and the annual superimposition rate (Linear

regression: $F = 30.72$; df = 1, 24; $P < 0.001$). The annual redd count explained 56% of the variation in the annual superimposition rate.

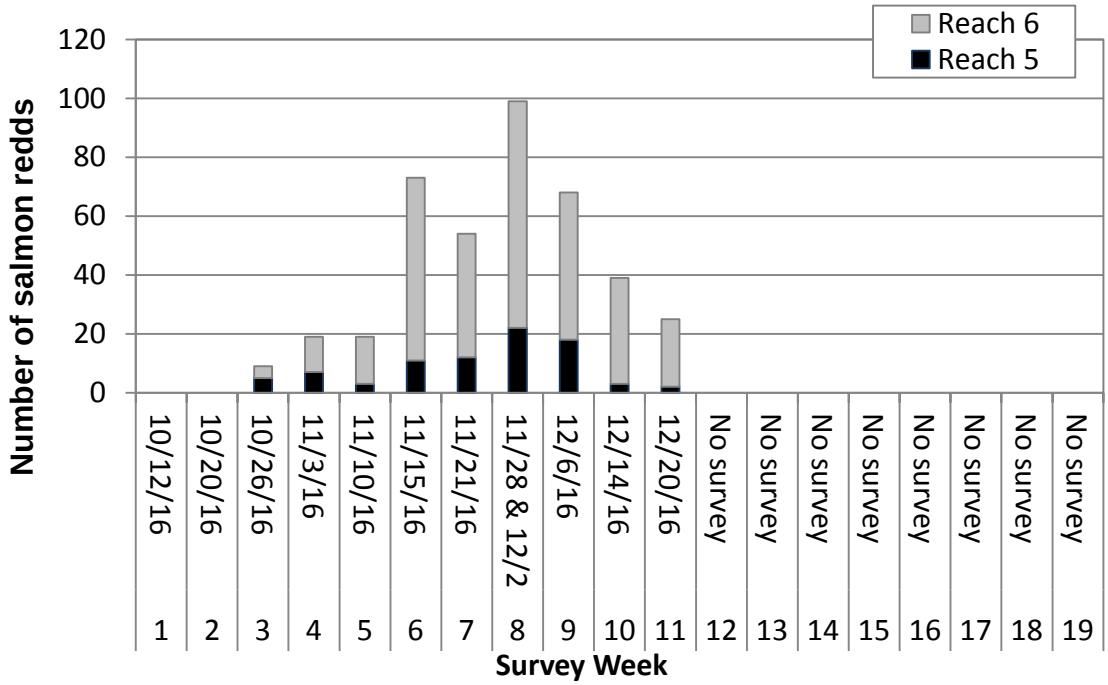

Figure 4. Weekly Chinook salmon redd totals by reach on the lower Mokelumne River during the 2016 surveys.

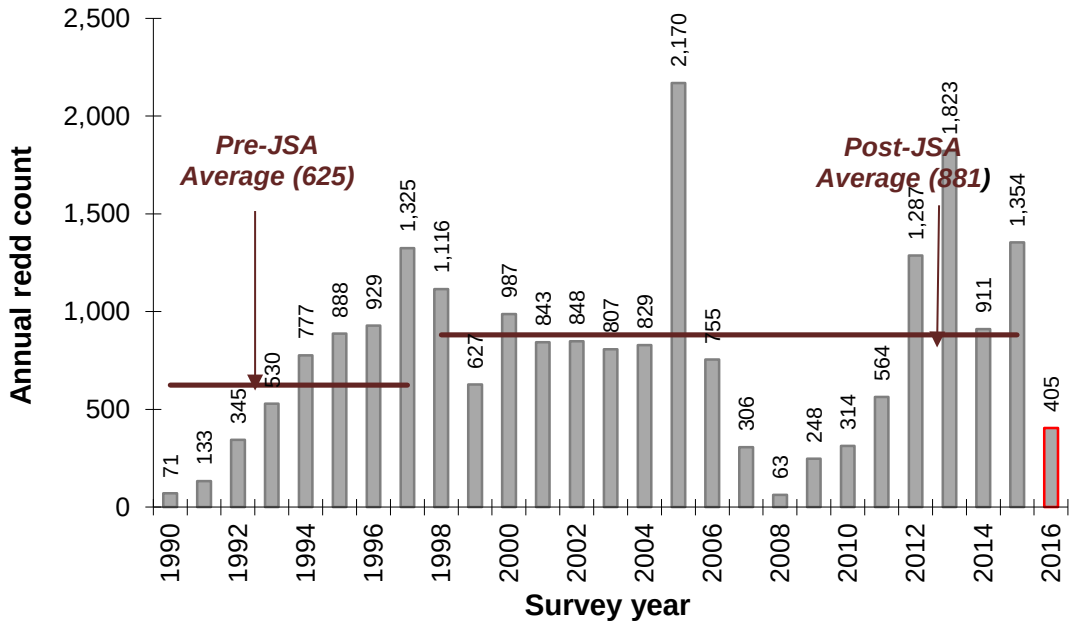

Figure 5. Chinook salmon redd totals on the lower Mokelumne River during pre-JSA flows (1990 – 1997), post-JSA flows (1998 – 2015), and for the 2016 survey season.

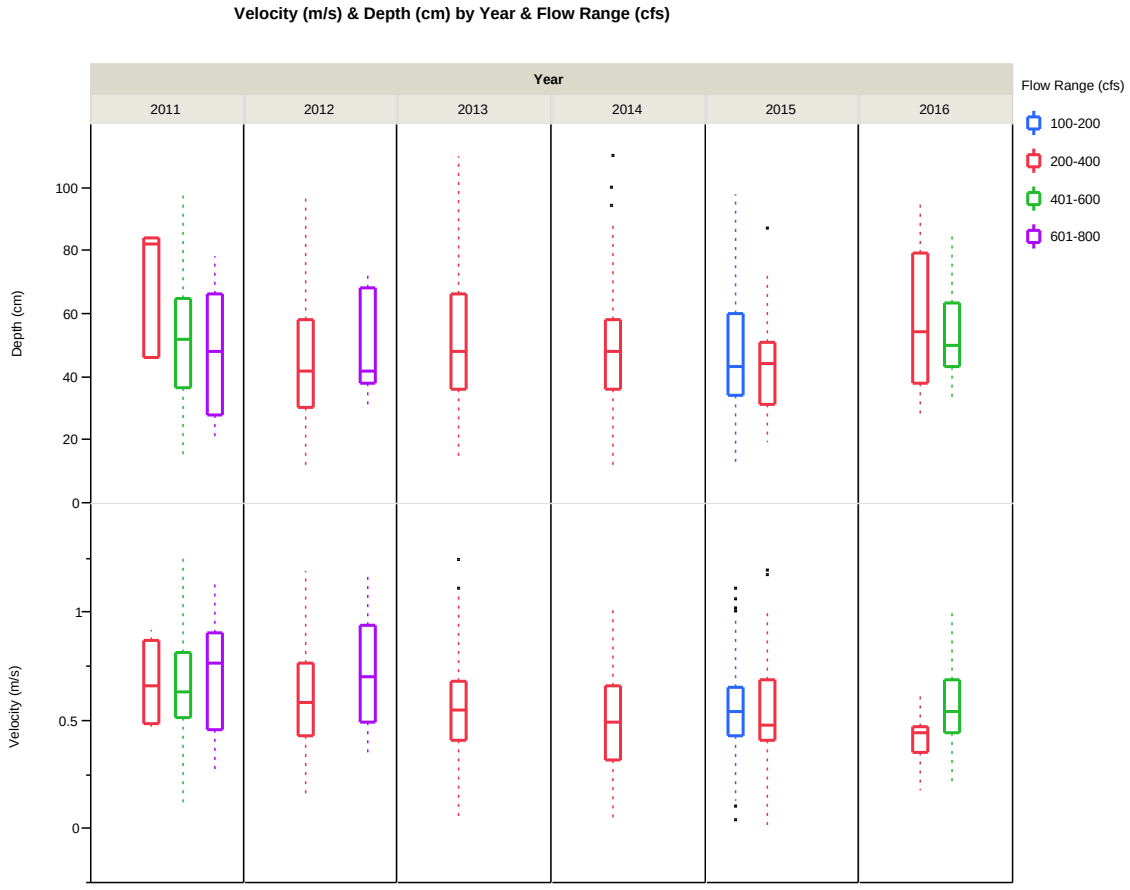

Figure 6. Boxplots of water depths and velocities measured just above the nose of Chinook salmon redds by survey year (2011-2016) and by flow range (100-200 cfs, 201-400 cfs, 401-600 cfs, 601-800 cfs) on the lower Mokelumne River.

Habitat use – water depth and velocity

Thirty-one water depth and velocity measurements were taken just above the nose of Chinook salmon redds from 3 November 2016 to 6 December 2016. Daily discharge from Camanche Dam ranged from 340 to 573 cfs on the dates the measurements were recorded. Chinook salmon redd water depths ranged from 28 to 96 cm and averaged 55 cm (SD = 18). The central 50% of measured redd depths (between Q1 and Q3) were between 42 and 64 cm. Water velocity measurements ranged from 0.18 to 1.02 m/s and averaged 0.51 m/s (SD = 0.19). The central 50% of measured redd velocities were between 0.4 and 0.64 m/s.

Flow range did not have a statistically significant effect on redd water velocity (two-way ANOVA: $F_{3, 693} = 2.01$, $P = 0.1115$) or redd water depth (two-way ANOVA: $F_{3, 685} = 1.07$, $P = 0.3601$) (Figure 6). However survey year did have a statistically significant effect on redd water depth (two-way ANOVA: $F_{5, 685} = 2.79$, $P = 0.0167$), and redd water velocity (two-way ANOVA: $F_{5, 693} = 4.57$, $P = 0.0004$).

Oncorhynchus mykiss

Redd totals

Four *O. mykiss* redds were detected during the 2016 salmonid redd survey. The first and last detections occurred on 6 December 2016 and 20 December 2016, respectively. The 2016 *O. mykiss* redd surveys ended prematurely after 20 December, as a result of Camanche releases exceeding 4,900 cubic feet per second.

Spawning habitat restoration site use

During the 2016 redd survey, two (50%) *O. mykiss* redds were found within the SHIRA reach. Overall, 3 *O. mykiss* redds, or 75% of the total number of redds detected (4), were constructed in SHR sites. One-hundred percent (3) of redds constructed in SHR sites were located in reach 6.

Superimposition

There were no observations of *O. mykiss* redds superimposed on other *O. mykiss* redds or Chinook salmon redds this season.

Habitat use – water depth and velocity

No water depth or velocity measurements were taken for *O. mykiss* redds this season.

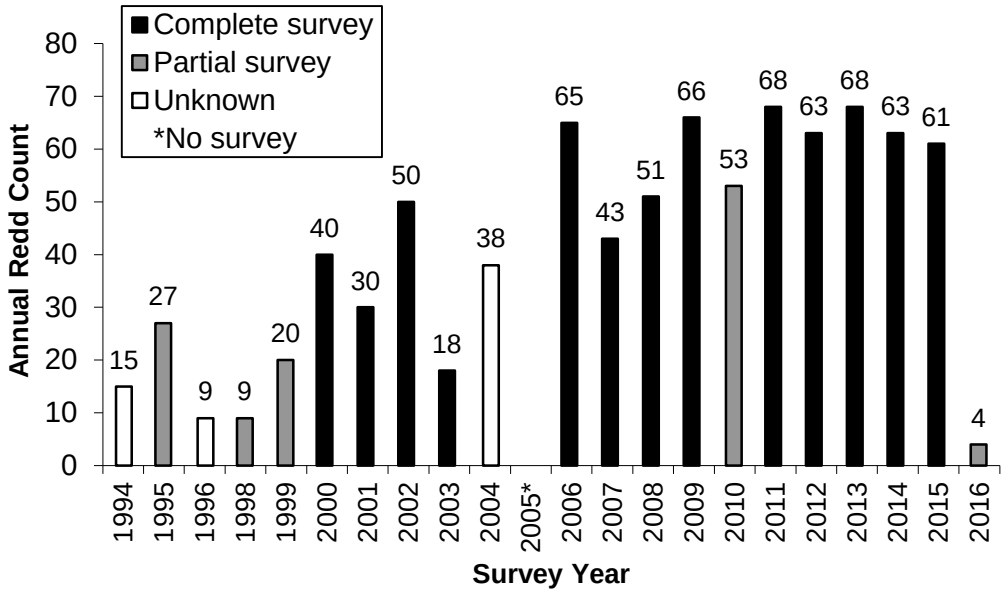

Figure 7. Annual *O. mykiss* redd totals on the lower Mokelumne River from 1994-2016.

DISCUSSION

Operating under an extremely wet water year, average and maximum daily surface and subsurface water temperatures for BY16 were lower than the Camanche hypolimnion threshold of 16.4°C when >95% of all Chinook salmon redds were constructed and throughout the incubation period. Although the threshold falls outside of the range necessary for maximum embryo survival (5 to 13°C) (McCullough 1999), a 50% survival rate (from fertilization to hatching) has been recorded for Chinook salmon embryos incubated at 16°C (Moyle 2002; McCullough 1999). Over the prior five spawning and incubation seasons (2012-2016), average daily hyporheic water temperatures typically fell within the range of surface water temperatures recorded at the McIntire and Elliot Rd. gauges, regardless of burial depth. These data indicate that the range of average daily surface water temperatures provided by the McIntire and Elliot gauges may provide a good general estimate of subsurface water temperatures for incubating Chinook salmon embryos. It is recommended to continue collecting and comparing subsurface and surface water temperatures over a variety of water years in an attempt to detect other possible trends. These data may be used to assess management strategies for cold water releases from Pardee Reservoir and Camanche Dam during the early stages of the Chinook salmon embryo incubation period.

The 2016 LMR Chinook salmon escapement estimate of 8,871 was 183% of the historical (1940-2015) average of 4,853, 258% of the pre-JSA (1940-1997) average of 3,439, and 98% of the post-JSA (1998-2015) average of 9,018. Preliminary 2016 escapement data from GrandTab[1] indicate that 132,474 fall-run Chinook salmon returned to the California Central Valley this season. This included 106,141 salmon that returned to the Sacramento River system and 26,333 salmon that returned to the San Joaquin River system. This season, the LMR accounted for 34% of the total return to the San Joaquin River system, which includes the Cosumnes River, the LMR, the Stanislaus River, the Tuolumne River, and the Merced River.

The 2016 Chinook salmon redd total was lower than all but two of the annual redd counts over the last two decades, although the survey was truncated due to high flows. The redd count was lower than the post-JSA average of 881. Roughly 52% of the returning population was adult salmon. A larger proportion (78%) of returning Chinook salmon was trapped at the hatchery this season, when compared to 2015 (64%) and 2014 (73%). The other 22% of the population (1,984 salmon) remained in the LMR. Peak spawning on the LMR was typical, occurring between the middle and end of November.

One of the primary objectives of EBMUD's ongoing habitat rehabilitation projects are to supplement depleted coarse sediment with suitable-sized spawning gravel in the LMR. These projects are intended to improve and expand spawning habitat for adult Chinook salmon and steelhead in the LMR. As of 1990, EBMUD has completed 24 annual spawning habitat rehabilitation projects in reaches 5 and 6 of the LMR in cooperation

[1] California Department of Fish and Game - Fisheries Branch Anadromous Assessment, http://www.calfish.org/ProgramsData/Species/CDFWAnadromousResourceAssessment.aspx, accessed on 3/30/2017.

with federal agencies, state agencies, local partnerships, and public organizations. These projects continue to provide high-quality spawning habitat as demonstrated by the large percentage of salmon redds constructed within the SHIRA reach (40.5% this season) and within all SHR sites (55.1% this season).

The 2016 Chinook salmon redd superimposition rate of 6.7% was lower than the long term average (1991-2015) of 10.6%. Spawning density (using annual redd counts) explained 60% of the variation in the annual salmon redd superimposition rate. During the 2016 spawning season, the Chinook salmon redd count was much lower than the long-term average, likely resulting in a lower than average superimposition rate.

Most of the Chinook salmon redd water depths and velocities recorded this season fell within the expected ranges for the species (Moyle 2002). Flow range did not have a statistically significant effect on Chinook salmon redd water velocity or water depth from 2011-2016. However, survey year did have a significant effect on redd water velocity and redd water depth. These results suggest that the selection for several physical spawning habitat parameters (water depth and velocity) is relatively consistent despite variable flows ranging from 100-800 cfs. However, there may be variation among brood stocks and other potential sources of annual environmental variation.

Four *O. mykiss* redds were observed during the incomplete 2016 season. If surveys would have been possible, *O. mykiss* redd counts most likely would have been much higher. The hatchery had 719 adult *O. mykiss* (total length $\geq$ 16 in.) return, which was the largest total since Camanche Reservoir was built in 1963. This season, high flows, and challenging weather, only allowed for weekly redd surveys to be conducted through the end of December. Peak spawning of *LMR O. mykiss* typically occur from late January through the end of February. Also, given the mixed life history of *O. mykiss* in Central Valley streams, the difference between resident rainbow trout redds and winter-run steelhead redds could not be distinguished during the spawning surveys, and it is possible that some of the *O. mykiss* redds detected were constructed by resident fish (Zimmerman et al. 2009), some of which may be <16 inches in total length.

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